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INFORMATION TECHNOLOGY AND INNOVATION OUTPUTS: THE MISSING LINK OF SEARCH EVOLUTION

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ABSTRACT

Recent literature documents mixed findings on the impact of information technology (IT) investment on firm innovation outputs. We explain why firms with greater IT investment are more likely to search across boundaries in recombining knowledge, which has a curvilinear relationship with innovation outputs, and find empirical evidence corroborating our theory.

INTRODUCTION

Firms are heavily investing in IT today, in order to improve operational efficiencies and generate innovation outputs (Dong, He, and Karhade, 2013; Xue, Ray, and Sambamurthy, 2012). Recent IS research increasingly explores the relationship between IT investment and innovation outputs, such as new patent inventions or new products and services (Joshi, Chi, Datta, and Han, 2010; Kleis, Chwelos, Ramirez, and Cockburn, 2012). In general, this stream of research supports a linear and positive relationship between IT investment and innovation outputs. However, empirical puzzles exist as some studies report the innovation impact of IT investment to be statistically non-significant (Aral and Weill, 2007; Dong, Karhade, Rai, and Xu, 2013). We are motivated to resolve this puzzle by exploring the functional form of the relationship between IT investment and innovation outputs.

In this study, we propose that IT investment has a curvilinear (inverted U-shaped) relationship with innovation outputs. To deepen our understanding of the IT investment and innovation outputs relationship, we draw on the evolutionary theory (ET) of the firm (Nelson and Winter, 1982) and systematically explain the reasons why IT investment and innovation outputs relationship is likely to be curvilinear. ET has been widely used to explain the firm innovation process, a theoretical perspective largely not used in IS research. Based on the ET theoretical lens, we view innovation as the recombination of knowledge elements and suggest that firms' *search for knowledge recombination* (SKR) is the missing link in the relationship between IT investment and innovation outputs. In doing so, we open the black box of the IT investment-innovation outputs relationship by proposing the evolution of SKR as a mediating mechanism.

Specifically, we conceptualize IT investment as an evolutionary force leading to the variation of SKR in a boundary-spanning manner. Greater IT investment is theorized to break the

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retention of SKR sticking to the knowledge elements within existing boundaries. We systematically review the SKR literature and identify the following four important boundaries in SKR: technological, organizational, geographical and temporal. We hypothesize that (1) IT investment enables SKR across technological, organizational, geographical and temporal boundaries, and (2) SKR across these boundaries has an inverted U-shaped relationship with innovation outputs. We construct a panel data set to test the theory. We find IT investment to be associated with SKR across organizational, geographical and temporal boundaries. In turn, we also find SKR across technological, organizational, geographical and temporal boundaries to have an inverted U-shaped relationship with innovation outputs.

THEORY AND HYPOTHESES

SKR with new and extant knowledge elements generates innovation outputs, which helps firms resolve problems by generating innovative solutions (Nelson and Winter, 1982). Firms search for knowledge recombination in a space with multidimensional boundaries. Since firm search behavior is a result of variation and retention, path discontinuity in recombining knowledge elements can be understood as search behavior based on novel knowledge elements across boundaries, and path dependency is manifested by conservative search behavior with knowledge elements within boundaries (Rosenkopf and Nerkar, 2001). Thus, variation drives firms to search for knowledge recombination in a boundary-spanning manner, while retention maintains firms to search for knowledge recombination within existing boundaries.

Technological boundaries refer to the technological domains of knowledge, and *SKR across technological boundaries* recombines knowledge elements from unfamiliar domains (Fleming, 2001). *Organizational boundaries* refer to the organizational identity of knowledge creator, and *SKR across organizational boundaries* recombines knowledge elements that were created by other firms (Resenkopf and Nerkar, 2001). *Geographical boundaries* refer to the geographical location of knowledge creator, and *SKR across geographical boundaries* recombines knowledge elements that were created in other regions (Ahuja and Katila, 2004). *Temporal boundaries* refer to the temporal recency of knowledge, and *SKR across temporal boundaries* recombines knowledge elements that were generated recently (Katila, 2002).

Greater IT investment will introduce more variation in SKR by enabling a firm to search for knowledge elements across technological boundaries. IT can play a “knowledge brokering” role in discovering and obtaining the knowledge from a variety of technological domains (Alavi and Leidner, 2001). We propose that greater IT investment will enable a firm to search for knowledge recombination across technological boundaries, which consists of more distant knowledge elements from unfamiliar technological domains relative to similar knowledge elements from familiar technological domains.

H1: IT investment has a positive relationship with SKR across technological boundaries.

Greater IT investment will introduce more variation in SKR by enabling a firm to search for knowledge elements across organizational boundaries. Prior IS research has suggested that IT can help a focal firm to acquire and assimilate external knowledge from other firms in a boundary-spanning manner (Joshi et al., 2010). We propose that greater IT investment will enable a firm to search for knowledge recombination across organizational boundaries, which consists of more external knowledge elements from other firms relative to internal knowledge elements from the focal firm.

H2: IT investment has a positive relationship with SKR across organizational boundaries.

Greater IT investment will introduce more variation in SKR by enabling a firm to search for knowledge elements across geographical boundaries. With the help of IT, a firm can access knowledge resources distributed across remote geographies. We propose that greater IT investment will enable a firm to search for knowledge recombination across geographical boundaries, which consists of more knowledge elements from other locations relative to knowledge elements from the same location where the focal firm is.

H3: IT investment has a positive relationship with SKR across geographical boundaries.

Greater IT investment will introduce more variation in SKR by enabling a firm to search for knowledge elements across temporal boundaries. IT allows a firm to access newly created knowledge in a timely manner. We propose that greater IT investment will enable a firm to search for knowledge recombination across temporal boundaries, which consists of more new knowledge elements relative to old knowledge elements.

H4: IT investment has a positive relationship with SKR across temporal boundaries.

Next, we discuss how SKR across boundaries will affect innovation outputs. On the one hand, technological breakthrough often occurs across knowledge domains (Fleming, 2001). On the other hand, recombination with similar knowledge elements within a technological domain is, on average, more successful (Fleming, 2001). Overall, as SKR across technological boundaries increases, a firm's innovation outputs will be beneficial up to a certain level. Beyond that point, innovation outputs are likely to drop with more SKR across technological boundaries.

H5: SKR across technological boundaries has an inverted U-shaped relationship with innovation outputs.

On the one hand, acquisition of external knowledge is critical for producing innovation (Cohen and Levinthal, 1990). On the other hand, extensive search for external knowledge may overlook internal knowledge and hurt knowledge recombination prospects with internal knowledge (Rosenkopf and Nerkar, 2001). Overall, as SKR across organizational boundaries increases, a firm's innovation outputs will be benefited up to a certain level. Beyond that point, innovation outputs are likely to drop with more SKR across organizational boundaries.

H6: SKR across organizational boundaries has an inverted U-shaped relationship with innovation outputs.

On the one hand, SKR beyond geographical restrictions can raise a firm's awareness and usage of knowledge elements from a varied set that is useful to solve the problems in different locations (Ahuja and Katila, 2004). On the other hand, searching too widely can be dysfunctional

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in generating innovation due to increased complexity of handling knowledge elements in distinct geographical contexts (Lahiri, 2010). Overall, as SKR across geographical boundaries increases, a firm's innovation outputs will be beneficial up to a certain level. Beyond that point, innovation outputs are likely to drop with more SKR across geographical boundaries.

H7: SKR across geographical boundaries has an inverted U-shaped relationship with innovation outputs.

On the one hand, different from old knowledge that has been exploited for a long time, new knowledge provides more recombinant opportunities (Katila, 2002). On the other hand, exclusive reliance on new knowledge may reduce the productivity of innovation by inducing unreliable or unfamiliar knowledge elements (Katila, 2002). Overall, as SKR across temporal boundaries increases, a firm's innovation outputs will be beneficial up to a certain level. Beyond that point, innovation outputs are likely to drop with more SKR across temporal boundaries.

H8: SKR across temporal boundaries has an inverted U-shaped relationship with innovation outputs.

METHODS AND RESULTS

We collect data from three archival sources. First, we started to construct the sample based on IT investment data from *InformationWeek* 500 (IW 500). *InformationWeek* reported annual IT spending information for the top 500 U.S. IT users from 1991 to 1997, which has been widely used to measure IT investment in IS research. IW 500 was regarded as the most reliable public source of IT investment data, providing a good surrogate of firm-level IT use. Second, we restricted the sample to public listed firms and matched IW 500 data to Standard and Poor's Compustat database by company names to obtain the financial data for a set of variables. Finally, we followed prior research and used patent as a proxy of knowledge held by the firm. We merged the data obtained earlier to the National Bureau for Economic Research (NBER) Patent Citations database (Hall, Jaffe, and Trajtenberg, 2001). NBER Patent Citations database was developed based on the raw data from the U.S. Patent and Trademark Office (USPTO), which provides detailed information for more than 3 million U.S. patents granted between 1976 and 2006 and almost 24 million citations made by these patents. We first aggregated patent-level patent data to the assignee level, and then to the firm level, and matched firm-level data to Compustat database by firms' GVKEYs. After merging the three sources of data, we constructed an unbalanced panel data set of 785 firm-year observations for 243 unique firms in 7 years. A longitudinal design with lagged dependent variables is used to avoid reverse causality and alleviate endogeneity concerns. Specially, IT investment is measured in one year before SKR, and innovation outputs are measured in a three-year period after SKR. We control R&D investment, search extent, search diversity, uncertainty, related diversification, unrelated diversification, debt ratio, sales growth rate, firm size, and industry and time dummies. Details of our measures are available upon request.

To test H1 to H4, one-year forward lagged SKR across technological, organizational, geographical and temporal boundaries were used as the dependent variables. These dependent variables are simultaneously determined by IT investment and other firm characteristics, leading the error terms of the four equations to be correlated. To address this issue, we used seemingly

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unrelated regression to estimate these four equations simultaneously. IT investment did not have a statistically significant effect on SKR across technological boundaries ($\beta_1 = 0.359$, $p > 0.1$). Thus, **H1 was not supported**. However, IT investment had statistically significant and positive effects on SKR across organizational, geographical and temporal boundaries ($\beta_2 = 0.434$, $p < 0.1$; $\beta_3 = 1.029$, $p < 0.1$; $\beta_4 = 0.344$, $p < 0.01$). Thus, **H2, H3 and H4 were supported**.

To test H5 to H8, innovation outputs in a three-year future period were used as the dependent variables. SKR across boundaries and their squared terms were the independent variables. Given that innovation outputs are count variables, we used Poisson regression and negative binominal regression to estimate the model. Poisson regression (reported here) and negative binomial regression showed that SKR across technological, organizational, geographical and temporal boundaries had statistically significant and positive effects on innovation outputs ($\beta_5 = 1.057$, $p < 0.1$; $\beta_6 = 87.161$, $p < 0.01$; $\beta_7 = 2.971$, $p < 0.01$; $\beta_8 = 16.907$, $p < 0.01$) and their squared terms had statistically significant and negative effects on innovation outputs ($\beta_9 = -2.644$, $p < 0.01$; $\beta_{10} = -48.720$, $p < 0.01$; $\beta_{11} = -2.159$, $p < 0.01$; $\beta_{12} = -19.145$, $p < 0.01$), suggesting inverted U-shaped relationships. Thus, **H5, H6, H7 and H8 were supported**.

CONCLUSION

Drawing on ET, we conceptualize IT investment as an evolutionary force inducing variation of SKR in a boundary-spanning manner. We find that greater IT investment is associated with more extensive SKR across organizational, geographical and temporal boundaries. However, IT investment is not associated with SKR across technological boundaries. This finding suggests that IT, as a boundary-spanning tool, is often used by firms to overcome organizational, geographical and temporal barriers in search, while the technological domains of knowledge is not mainly driven by the use of IT. Furthermore, we find an inverted U-shaped relationship between SKR across boundaries and innovation outputs. This may be because the ambidexterity of firm search behavior can take advantage of knowledge elements both across and within boundaries, and therefore generate more innovation outputs. Heavy reliance on the knowledge elements within boundaries will hinder recombination, similar to the case of heavy reliance on the knowledge elements across boundaries. This finding reveals the mechanisms through which IT investment affects innovation outputs and the specific nonlinear nature of the relationship. Future research should continue to explore the nonlinear nature of relationship between IT investment and innovation outputs, and more broadly other outcomes.

ENDNOTES

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